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NAVAL POSTGRADUATE SCHOOL
Monterey, California

DEVELOPMENT OF REGIONAL EXTREME MODEL ATMOSPHERES FOR AEROTHERMODYNAMIC CALCULATIONS (II)

by

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ABSTRACT

In an earlier paper (Model Atmospheres (I)), a procedure was developed for determining the most probable vertical temperature profile associated with the occurrence of 1% global temperature extreme at mandatory-pressure levels at stations in the North American Arctic. The same technique, based upon a variation of the stepwise multiple regression procedure, was employed in the current study. Whereas the radiosondes investigated in Model Atmospheres (I) consisted entirely of "checked-data" quality, those stations designated for study in this work required a much more refined data-screen, due to lack of initially checked radiosonde report quality. Nevertheless, after application of various acceptability criteria, the radiosondes at each station were arranged in the same format as employed in Model Atmospheres (I). There remained in each case a suitable sample population to provide significant results. The ensuing multiple regression analysis applied to the geographically and climatologically diverse set of stations of the current study led to realistic estimates of the temperature profiles which were conditionally dependent upon the existence of 1% extreme forcing-level temperature T_J at previously designated pressure levels p_J.

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1. Introduction

The present work frequently to be abbreviated in what follows as Model Atmospheres (II) is a sequel to a research report Model Atmospheres (I) by Martin (1972). The latter report dealt with the development of vertically-consistent temperature profiles which are contingent upon the simultaneous existence of a known temperature (at the 1% probability level) at certain designated stations and for correspondingly known elevations. The complete set of stations and levels for which these tentative MIL-STD-210 temperature extremes were considered to exist are shown in Table 1 after Sissenwine (1970, personal communication) for both the cold- and warm-extreme cases. The extreme-sounding envelopes are also shown in Fig. 1 for January and July climatology.

Model Atmospheres (I) dealt with those extreme sounding sites and levels of Table I indicated by asterisk symbols, which stations were located in the North American Arctic Basin. Multiple regression procedures were developed for specifying the vertical temperature profiles at these North American Arctic stations. All of the stations analyzed in Model Atmospheres (I) were characterized by radiosonde data of high quality and by a type of quality control termed "checked data" processing. Furthermore, all of these Model Atmosphere (I) cases had temperature-height listings in the concise pressure-level format p_k , k=1,.....,21, with p_k ranging from 1000 mb to 100 mb as shown in Table 2. This concise arrangement of the T(p)-profiles made possible a simple system for application of the regression procedures so successfully developed in this earlier report. Model Atmospheres (I) thus served as a useful pilot project for the development of mean temperature profiles for those stations not indicated by the asterisk symbol in Table 1, which station-data has become the basis of the analysis of the present paper.

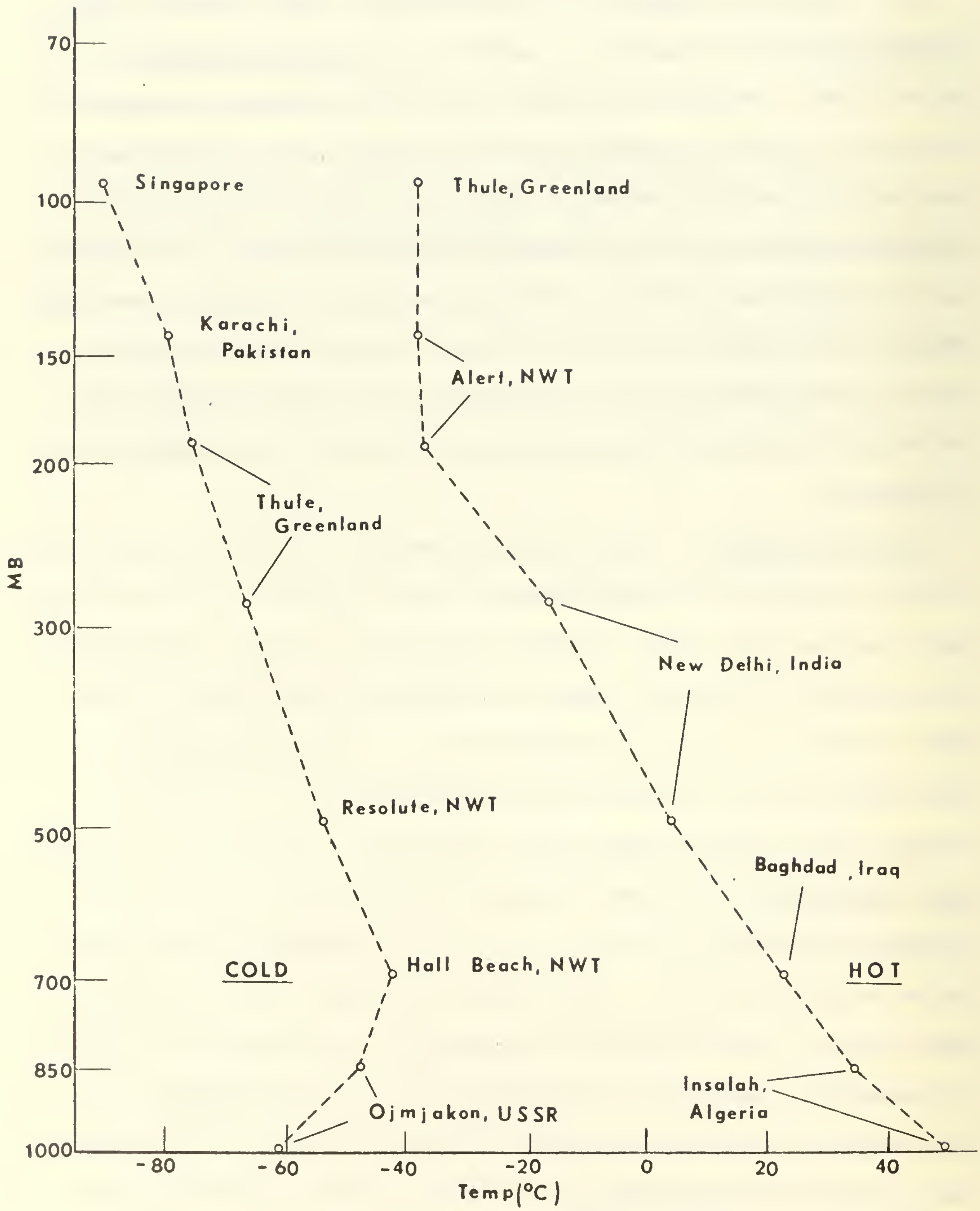

Fig. 1. Preliminary version of the MIL-STD-210B Atmosphere adopted for use in this study (after Sissenwine, 1970).

TABLE 1. Locations of proposed extreme temperatures in the cold world-wide and warm world-wide cases (after Sissenwine, 1970).

	Cold-Extreme				Warm-Extreme			
Level	Location	January Mean (^{o}C)	STD. DEV. (^{o}C)	1% Extreme (^{o}C)	Location	July Mean (^{o}C)	STD. DEV. (^{o}C)	1% Extreme (^{o}C)
SFC	Ojmjakon, USSR	-50.6	4.4	-60.6	Insalah, Algeria	40.9	3.9	49.0
850mb	Ojmjakon, USSR	-35.1	5.5	-47.0	Insalah, Algeria	28.9	2.2	34.0
700mb	Hall Beach,* NWT	-27.3	6.5	-42.4	Baghdad, Iraq	17.0	2.2	22.1
500mb	Resolute,* NWT	-43.0	4.6	-53.2	New Delhi, India	-4.3	3.9	4.0
300mb	Thule,* Greenland	-60.6	2.2	-66.0	New Delhi, India	-25.8	3.9	-16.0
200mb	Thule,* Greenland	-59.7	7.2	-75.0	Alert,* NWT	-42.3	2.5	-36.5
150mb	Karachi, Pakistan	-65.0	6.0	-79.0	Alert,* NWT	-43.3	2.5	-37.5
100mb	Singapore	-81.0	2.2	-86.0	Thule,* Greenland	-43.8	2.2	-37.2

TABLE 2. Arrangements of sounding temperatures and heights by pressure levels k=1,...,2, in each sounding.

	k = 1	2	3	4	5	k=6	
	1000mb	950	900	850	800	750	
k = 7	700	650	600	550	450	450	k = 12
k = 13	400	350	300	250	200	175	k = 18
k = 19	150	125	100				
	k = 19	20	21				

The organization of Model Atmospheres (II) proceeds first with the remaining January cold-extreme cases of Table 1. In the second phase, the July warm-extreme cases are considered. No attempt is made in this paper to restate specific results of Model Atmospheres (I).

Grateful acknowledgements to the Commander, Naval Weather Service Command should be made at the outset for providing all of the data tapes for the stations listed in Table 1 from the original data-tape archives. The capable technical assistance of the Naval Weather Service Environmental Detachment, Asheville, North Carolina, is also acknowledged. All data-samples provided were based upon the period 1967-70 inclusive.

Certain problems of data inaccuracy occurred in connection with all of the soundings of the present study in both the summer and winter cases. The elimination of data inaccuracies is the subject of Section 2.

2. Data processing.

The primary data deficiencies in the soundings considered in this paper as contrasted with those of Model Atmospheres (I) were

(i) the relative scarcity of complete soundings particularly due to missing data below the 850 mb level, and above the 200 mb level.

(ii) inconsistency in the number of reporting levels: in some cases, complete soundings included only data at mandatory levels. In others, the number of temperature-reporting levels seemed excessive beyond possible significance.

(a) Testing and development of vertically-consistent soundings.

In maximizing the information content of individual soundings, invaluable assistance was volunteered by Mr. Donald C. Schertz of the Naval Environmental Prediction Research Facility of Monterey, California. Mr. Schertz subjected all of the taped soundings to a computer-editing

program designed to scan each sounding iteratively between reported levels. The main objective was to arrive at hydrostatically consistent values of the reported virtual temperatures and heights at indicated pressure levels. In doing this, superadiabatic lapse rates above 850 mb were eliminated. Finally, the originally listed sounding and the edited sounding were printed out in succession so that apparent errors in the original were easily recognizable. Even if the change listed by the editing program was not accepted, the indicated change pointed out the location of the problem data-level. In this case, maximum weight was attached to the hydrostatic thickness equation

$$Z_B - Z_A = \frac{T_{VA}}{\gamma_{AB}} \left[1 - \left(\frac{p_B}{p_A}\right)^{(R_d \gamma_{A,B})/g}\right] \tag{1}$$

where p_A, p_B are successive pressure levels in the vertical, T_{VA} is the <u>virtual temperature</u> at the base of the layer being tested, and $\gamma_{A,B}$ is the lapse rate of virtual temperature between p_A and p_B. The virtual temperature T_{VB} at the upper level is then given by

$$T_{VB} = T_{VA} - \gamma_{A,B}(Z_A - Z_B) \tag{2}$$

The conversion between $T(p)$ and $T_V(p)$ is given by

$$T(p) = \frac{T_V(p)}{1 + \frac{.378033}{p} \exp\left[21.656 - \frac{5418.}{T_D}\right]} \tag{3}$$

where $T_D(p)$ is the listed dewpoint temperature ($^{\circ}$K) at level p. The denominator of (3) reduces essentially to unity when $p \leq 500$ mb.

When T(p) was available at p = 200 mb but not at higher levels, a "bootstrap" regression procedure was utilized to generate T(100). This was done by utilizing a regression equation for T(100) in terms of predictors

at all uniform temperature-levels (similar to those of Table 2) below p = 200 mb. This procedure generally led to good specification of T(100) for the dependent sample, and also to reasonable values of T(100) when the latter was originally listed as missing.

For any sounding case not discarded by gross-error checks, if a temperature T(p) was missing at a designated level p_k of Table 2, the temperature $T(p_k)$ was interpolated using the hydrostatically-consistent equations (1), (2), (3) with $p_A \geq p_k \geq p_B$. This procedure was also applied to the $T(p_k)$ values between 200 and 100 mb, when the latter had been generated by the regression method. In this case, it was also necessary to develop a value Z(100) first in order to apply Eq. 1. This was done by choosing as a first guess for the lapse rate the station sample-mean height $\bar{Z}$ (100), where

$$\gamma_{A,B} = \frac{T(200) - T(100)}{\bar{Z}_{100} - Z_{200}} \tag{4}$$

While Eq. 4 introduces some error in the lapse rate in the layer (100,200), the thickness-computation $\Delta Z(100,200)$ tends to be error-compensated. The resulting height computations are then used only in computation of $T(p_k)$ values at $Z(p_k)$ by Eq. 2 to fill out the temperature matrix of Table 2.

(b) The case of missing surface reports.

For the most part, the major effort of this study hinges on the use of surface temperature reports to determine the vertical structure above the surface. In approximately 25% of all cases listed in the station files, the surface temperature report was missing. In nearly all these cases, the entire sounding was discarded, since the temperature structure between 850 mb and the surface was usually extremely variable. Two exceptions occurred.

(i) New Delhi January soundings. Here the temperature profile to be determined was based upon a known initial value $T_J(150)$. The regression-generated profile could be determined in a large number of cases down to 850 mb. For the smaller subset of sounding cases containing surface reports, only surface means and standard deviations were computed since these mean results indicated the absence of extreme temperatures at the surface level.

(ii) Ojmjakon, USSR, January soundings. For this station, the surface inversion was so strong as to be a relatively consistent feature of the vertical profile below 850 mb. Since the 1000 mb heights were almost always listed, it was considered useful to determine the 1000 - 850 mb thickness, in the form

$$\bar{T}\,(1000,850) = \frac{Z(850) - Z(1000)}{\frac{R_d}{g}\left(\ln \frac{1000}{850}\right)} \qquad (5a)$$

and then to equate the result of (5a) to the height-weighted mean temperature defined by

$$\bar{T} = \frac{[Z(850) - 726.]\left(\frac{T(850) + T_s}{2}\right) + [726. - Z(1000)]\,T_s}{Z(850) - Z(1000)} \qquad (5b)$$

For Ojmjakon, the surface elevation $Z_s = 726.0$ meters was employed, and the terrain contribution to the mean temperature $\bar{T}$ was made isothermally at the value determined from Eq. (5b) for T_s.

The values of T_s resulting from Eq. 5 showed good agreement with the listed surface mean and standard-deviations of Table 1. The computation of T_s was highly dependent upon $\Delta Z(850,1000)$ and this parameter had to be carefully checked for invalid values. Such values usually arose from reported errors in Z(1000), which could be detected from an analysis of the time-sequencing of the Z(1000) reports, (i.e., by gross-error checks of Z(1000)).

After eliminating such thickness errors, the T_s-values were accurate enough to be specified at a highly significant level in terms of the overlying temperature variables in the format of Table 2.

As noted previously, virtually all other stations, e.g., Insalah and Baghdad, required definition of the surface temperature to consider the possibility of surface extremes. Hence, if the surface report were missing, the entire sounding was discarded. At Singapore, the data-quality was excellent and no data rejections were necessary.

The use of New Delhi January data was attempted solely as a substitute for Karachi, where preliminary indications (Table 1) led one to expect a cold extreme at 150 mb.

As a result of the data-processing outlined here, the following station sounding sets arranged in the format of Table 2 were developed:

Winter Sounding data.

Ojmjakon	Singapore	New Delhi (for Karachi)
169 cases	86 cases	158 cases, $p \leq 850$ mb,
		92 cases, surface and above

Summer Sounding data.

Insalah	Baghdad	New Delhi
72 cases	92 cases	159 cases

3. Development of regression-generated profiles, January extremes

The stepwise regression procedure of BIMED 02R was utilized in conjunction with the checked data files for each winter case station of this study. The procedure is virtually identical to that described in Model Atmospheres (I). The objective at each station was to develop by a modified least-squares technique the temperature specification for each T_M (temperature at

a mandatory level), where the temperature T_M successively assumes each of the indexed variables (from Table 2) listed below, apart from the forcing-level temperature.

T_1, the temperature at the surface

T_4, the temperature at 850 mb

T_7, the temperature at 700 mb

T_{11}, the temperature at 500 mb

T_{15}, the temperature at 300 mb

T_{17}, the temperature at 200 mb

T_{19}, the temperature at 150 mb

T_{21}, the temperature at 100 mb

The procedure then was to develop a least-squares fit for the specification of $T_M(P_M)$ in the form

$$T_M(p_M) = A_M + B_M T_J + C_M X_M \qquad (6)$$

where $T_J(p_J)$ is the temperature at the pressure level p_J where the extreme temperature listed in Table 1 occurs. The variable X_M represents a linear combination of up to 7 independent temperature variables, not including the forcing-level temperature T_J. The variable X_M involves temperature-predictors which are highly correlated with the dependent variable T_M. The variable T_J is forced into (6) at each step of the eight-step regression equation sought.

An analysis in the form of Eq. 6 will be applied to each of the following January station data files:

(A) Ojmjakon, $T_J = T_J(\text{Sfc})$

(B) Ojmjakon, $T_J = T_J(850)$

(C) Singapore, $T_J = T_J(100)$

(D) Singapore, $T_J = T_J(150)$

(E) New Delhi, $T_J = T_J(150)$

The regression-generated statistics for cases (A),(B),...,(E), include means, standard deviations, multiple correlation coefficients R and standard errors of estimate. The primary test of the specification procedure is through the least squares formula (6) which in general yields an R close to unity and a standard error much reduced from the standard deviation. Three analyses have been conducted in each case and these analyses are summarized in tabular form for each case.

These analyses are based essentially upon the regression procedure applied to (a) the full-sample of T_J-data, (b) the same regression to the 10% nominal extreme sample, and (c) to the 1% subsample extreme of T_J-values. A nominal extreme may be defined for each station and T_J according to the Gaussian probability percentiles

$$\begin{aligned} T_{.10}(p_J) &= \bar{T}_J \pm 1.2817\ \sigma_J \\ T_{.01}(p_J) &= \bar{T}_J \pm 2.3267\ \sigma_J \end{aligned} \qquad (7)$$

where the minus sign applies for the cold extreme. Values of T_J, σ_J are taken from the full-sample analyses in part (a) of each table. In each of tables a,b is shown also the regression statistics R and σ_E, where

R is the multiple correlation coefficient

$$\sigma_E = \sigma_J \sqrt{1 - R^2}$$

with σ_E the standard error, after application of the specification equation for T_M.

It is to be noted that in tables 3,4,...,7 below that there is little systematic deviation in the standard errors resulting from treatment (b) relative to that for the full-sample treatment (a). These results give credibility to the requirement of a meaningful forcing-level temperature T_J.

However, in most cases, the requirement of a 1% extreme of T_J does not yield a significantly different vertical profile, level for level, from that required by the existence of a 10% extreme of T_J. This appears to be due to the surprisingly small standard deviations at T_M-levels for the stations under consideration here, which is in sharp contrast to the rather large standard deviations in the Model Atmospheres (I) study.

3(A). Ojmjakon, T_J(Sfc).

The results for the three-subsample stratifications are shown in Tables 3a,b,c. It is to be noted that the 1% extreme listed here is -61.3°C which is colder than that of Table 1. However, in part (b), the 20% subsample has been analyzed rather than the 10% subsample normally to be treated under part (b). This is due to the emphasis (AFCRL, 1973) placed upon the "coldest feasible operating" surface temperature of -51°C, which corresponds to $T_{.20}$(Sfc) at Ojmjakon. A consistent deviation between the $\overline{T}_M$(c) and $\overline{T}_M$(b) profiles does appear in Table 3 in that the low-level temperatures are slightly colder in the former case, and become somewhat warmer at high elevations ($p \leq 150$ mb). The essence of these tabular comparisons may be visualized by examining Fig. 2.

3(B). Ojmjakon, T_J(850.

A similar set of comparisons, level for level, may be made by examination of Table 4 (a,b,c). The graphs of Fig. 3 show that the $T_{.01}$(850) atmosphere tends to remain colder than the mean at all levels below $p = 150$ mb, but then tends to become slightly warmer at $p = 100$ mb.

3(C). Singapore, T_J(100).

Here we examine the winter extreme atmosphere models from the tropospheric top rather than from the base. It is to be noted that observed 1% extreme T_J(Table 5) is colder than that listed in Table 1. Fig. 4 illustrates

TABLE 3. Regression statistics at mandatory pressure levels at Ojmjakon, USSR , using T_J = T(Sfc) as the forcing-level January temperature. Part (a) refers to the full-data January sample; part (b) refers to the nominal 20% cold extreme sample of T(Sfc); part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme cold set of T(Sfc). All reports are based upon a set of twice daily rawinsondes observed during 1967-70.

Level	(a) N = 169 cases				(b) N = 37 cases				(c) N = 3
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \leq T_{.01}$
Sfc	-44.35	8.276			-55.36	3.084			-61.3
850	-32.70	7.493	.9761	1.680	-38.00	5.708	.9343	2.094	-35.6
700	-27.53	5.437	.9927	0.671	-30.68	4.159	.9846	0.747	-32.5
500	-39.59	4.365	.9972	0.333	-41.99	2.379	.9980	0.151	-42.7
300	-57.92	3.529	.9497	1.132	-58.81	3.001	.9534	0.931	-60.3
200	-55.95	4.934	.9950	0.507	-56.57	3.624	.9972	0.281	-56.7
150	-54.45	4.614	.9986	0.247	-55.84	4.380	.9998	0.088	-55.4
100	-53.23	5.001	.9973	0.380	-55.38	5.843	.9999	0.102	-54.2

*The surface level was at an elevation of 726 meters

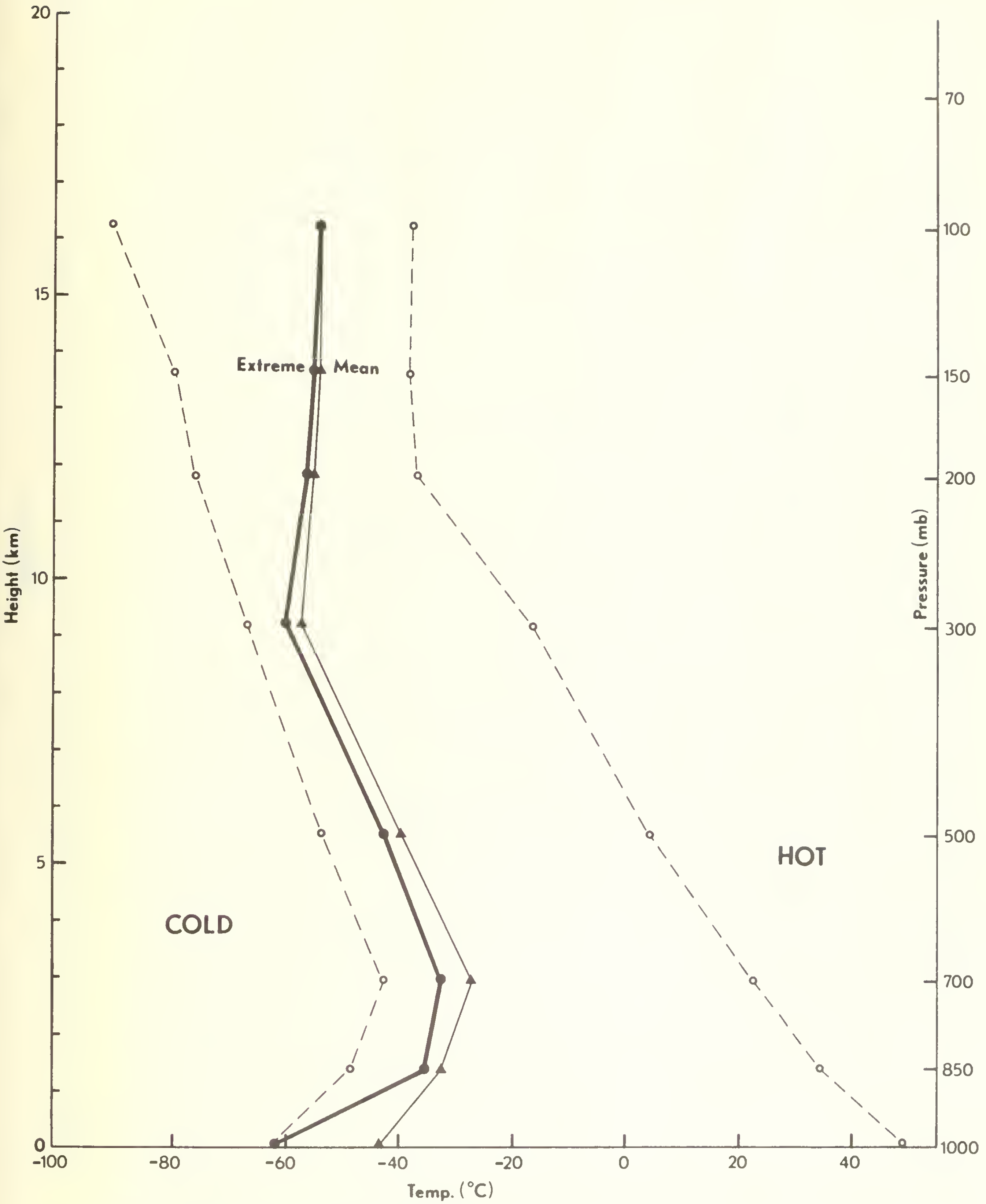

Fig. 2. Regression-generated mean January temperature profiles over OJMJAKON, USSR, corresponding to the forcing-level temperature T_J(Sfc). The heavy solid profile is based on the 1% cold extreme sample at the surface. Both profiles are based upon values listed in Table 3.

TABLE 4. Regression statistics at mandatory pressure levels at Ojmjakon, USSR , using $T_J = T(850)$ as the forcing-level January temperature. Part (a) refers to the full-data January sample; part (b) refers to the nominal 10% cold extreme sample of T(850); part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme cold set of T(850). The reports are based upon a set of twice-daily rawinsondes observed during 1967-70.

Level	(a) N = 169 cases				(b) N = 17 cases				(c) N = 2
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \leq T_{.01}$
Surface*	-44.35	8.276	.9878	1.329	-51.18	6.692	.9866	1.165	-56.05
850 mb	-32.70	7.493			-43.92	1.643			-46.7
700	-27.53	5.437	.9927	0.671	-31.62	4.833	.9886	0.778	-32.85
500	-39.59	4.365	.9972	0.332	-40.72	1.810	.9958	0.178	-41.5
300	-57.92	3.529	.9507	1.121	-57.62	2.978	.9460	1.032	-59.85
200	-55.95	4.934	.9950	0.506	-54.89	3.616	.9960	0.345	-56.3
150	-54.45	4.614	.9986	0.246	-53.93	3.679	.9998	0.076	-54.35
100	-53.92	5.001	.9972	0.379	-52.49	4.911	.9999	0.086	-52.7

* Surface elevation is actually at 726 meters

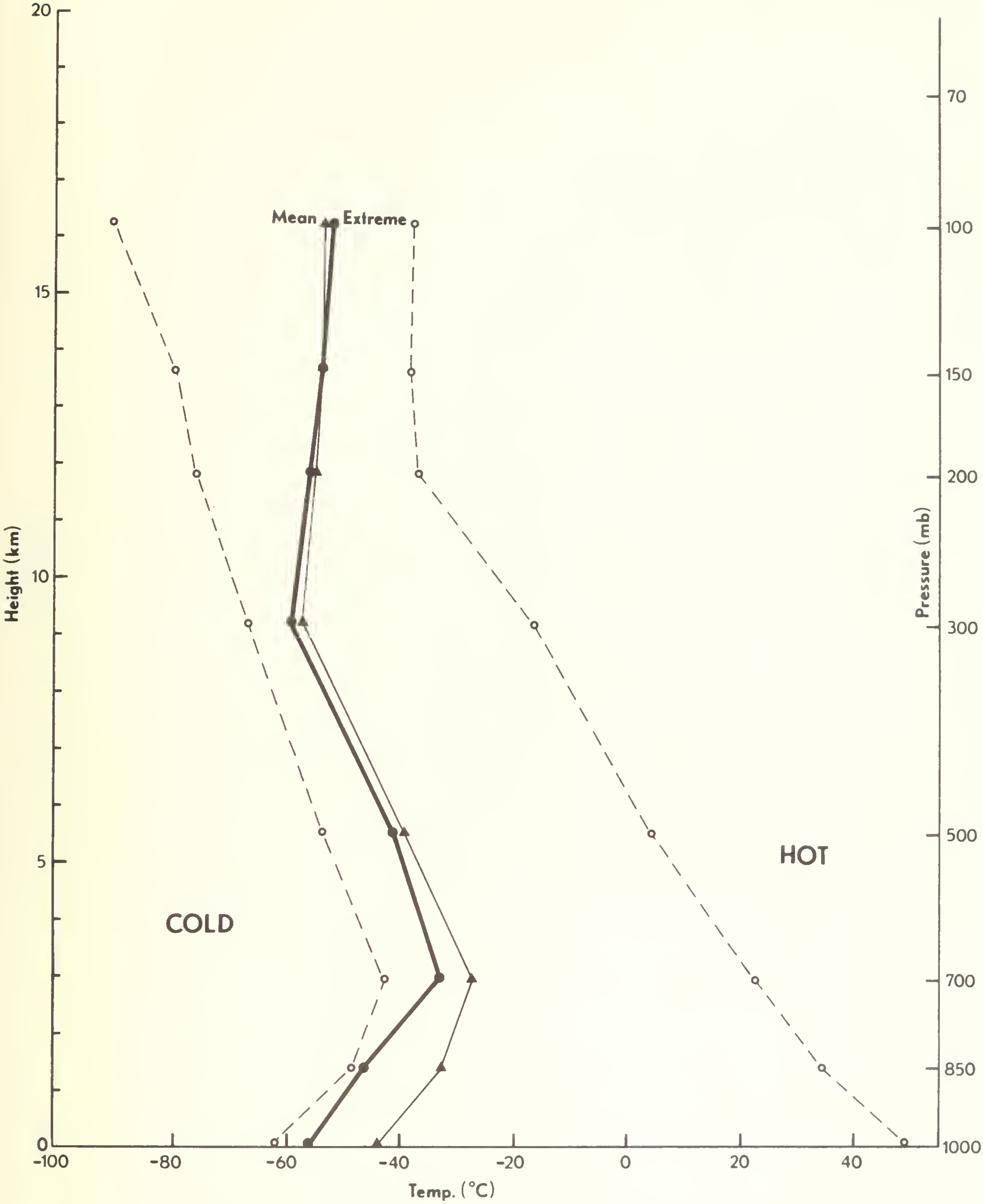

Fig. 3. Regression-generated mean January temperature profiles over OJMJAKON, USSR, corresponding to a forcing-level temperature $T_J(850)$. The heavy solid profile is based on the 1% <u>cold extreme</u> sample at 850mb. Both profiles are based upon values listed in Table 4.

TABLE 5. Regression statistics at mandatory pressure levels at Singapore, Malaysia, using $T_J = T(100)$ as the forcing-level January temperature. Part (a) refers to the full-data January sample; part (b) refers to the nominal 10% cold extreme sample of $T_J(100)$; part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme cold set of $T_J(100)$. All reports correspond to 1200 GMT rawinsondes (1967-70).

Level	(a) N = 86 cases				(b) N = 10 cases				(c) N = 2
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \leq T_{.01}$
*1000 mb	23.42	1.015	.9692	0.262	23.45	1.136	.9530	0.391	25.00
850	16.63	1.506	.9746	0.354	16.92	0.958	.9359	0.382	17.60
700	8.04	1.318	.9743	0.312	8.19	0.994	.9559	0.331	8.05
500	-7.07	1.941	.9628	0.551	-6.68	0.826	.8948	0.418	-6.75
300	-32.32	1.620	.9765	0.367	-33.23	1.742	.9755	0.435	-33.05
200	-54.59	2.068	.9831	0.398	-55.50	2.173	.9634	0.661	-56.55
150	-68.55	2.361	.9520	0.759	-69.09	1.851	.9370	0.734	-70.85
100	-81.39	2.811			-85.96	0.718			-87.1

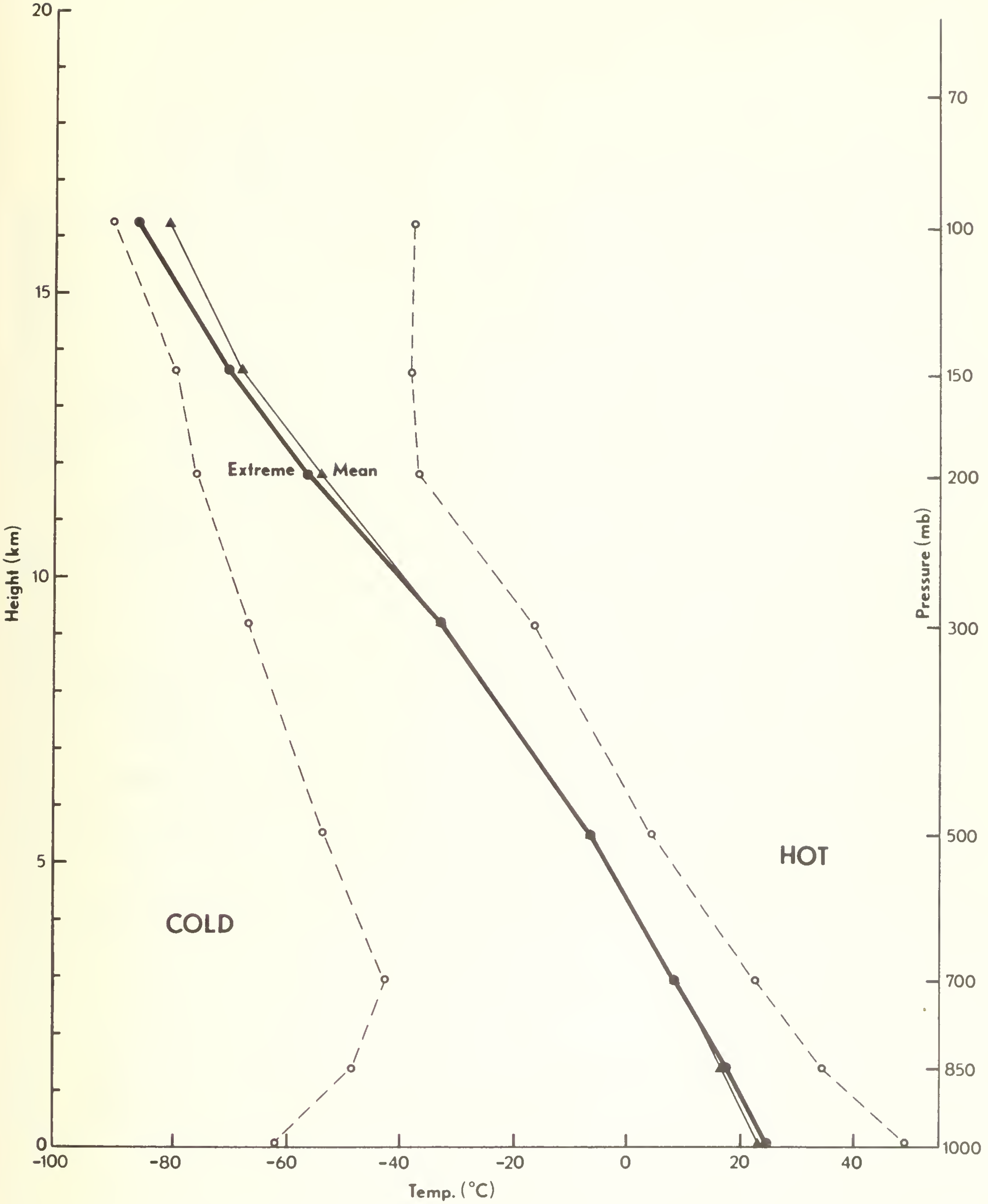

Fig. 4. Regression-generated mean January temperature profiles over Singapore corresponding to a forcing-level temperature $T_J(100)$. The heavy solid profile is based on the 1% cold extreme sample at 100 mb. Both profiles are based on values listed in Table 5.

the type of modification which may be expected between the $\overline{T}_M(c)$- and $\overline{T}_M(a)$-profiles, with the latter based upon the full-data sample. The former case is colder than the mean profile at Singapore to about 300 mb, and below this level becomes somewhat warmer.

3(D). Singapore, $T_J(150)$.

Table 6 is relevant. The test conducted here was done primarily because the Karachi data was unavailable in any useful volume or quality. The sample mean [case (a)] is cold for this level in agreement with meridional profiles of the climatological data (Crutcher, 1970) in the region between the equator to 25N in January. The assignment of the 1% cold extreme at 150 mb listed in Table 6 is characteristic of a cooler than normal upper troposphere, but case (c) shows a tendency toward a warmer mid-troposphere (e.g., at 500 and 700 mb). The nature of any profile deviations closer to ground level is not clear from the statistics of Table 6. Fig. 5 shows the comparison between the mean and "extreme" atmospheres. Another interesting result is that the case (c) extreme at 150 mb, $T_J(150) = -74.3\ ^{o}C$ corresponds to $T_M(100) = -82.0\ ^{o}C$ which is considerably warmer than the climatological extreme $T_{.01}(100) = -87.1\ ^{o}C$ noted in Section 3(D).

3(E). New Delhi, $T_J(150)$.

Again this case was tested primarily as a substitute for $T_{.01}(150)$, originally listed in Table 1 as occurring at Karachi. However, there was no reliable data at Karachi. The part (a,b,c) regression results for New Delhi are listed in Table 7 for 100 mb,.....,850 mb, levels only. The listed 1% extreme $T_{.01}(150) = -70.7\ ^{o}C$ at New Delhi is far warmer than that of Table 2 for Karachi ($-79\ ^{o}C$). The latter extreme presumably has been incorrectly estimated because of the large standard error attributed

TABLE 6. Regression statistics at mandatory pressure levels at Singapore, Malaysia, using $T_J = T(150)$ as the forcing-level January temperature. Part (a) refers to the full-data January sample; part (b) refers to the nominal 10% cold extreme sample of T(150); part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme cold set of T(150). All reports are based 1200 GMT rawinsondes (1967-70).

Level	(a) N = 86 cases				(b) N = 9 cases				(c) N = 1
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \leq T_{.01}$
1000 mb	23.42	1.015	.9685	0.266	23.22	2.103	.9902	0.339	21.2
850	16.63	1.506	.9747	0.354	16.87	1.323	.9831	0.279	17.6
700	8.04	1.318	.9754	0.305	7.47	0.843	.8469	0.517	8.6
500	-7.07	1.941	.9623	0.555	-6.90	0.974	.9219	0.447	-4.9
300	-32.32	1.620	.9769	0.364	-33.62	0.812	.9045	0.400	-32.9
200	-54.59	2.068	.9833	0.396	-57.36	0.859	.8442	0.532	-58.0
150	-68.55	2.361			-72.34	0.919			-74.3
100	-81.49	2.811	.8050	1.752	-81.50	3.259	.8819	1.774	-82.0

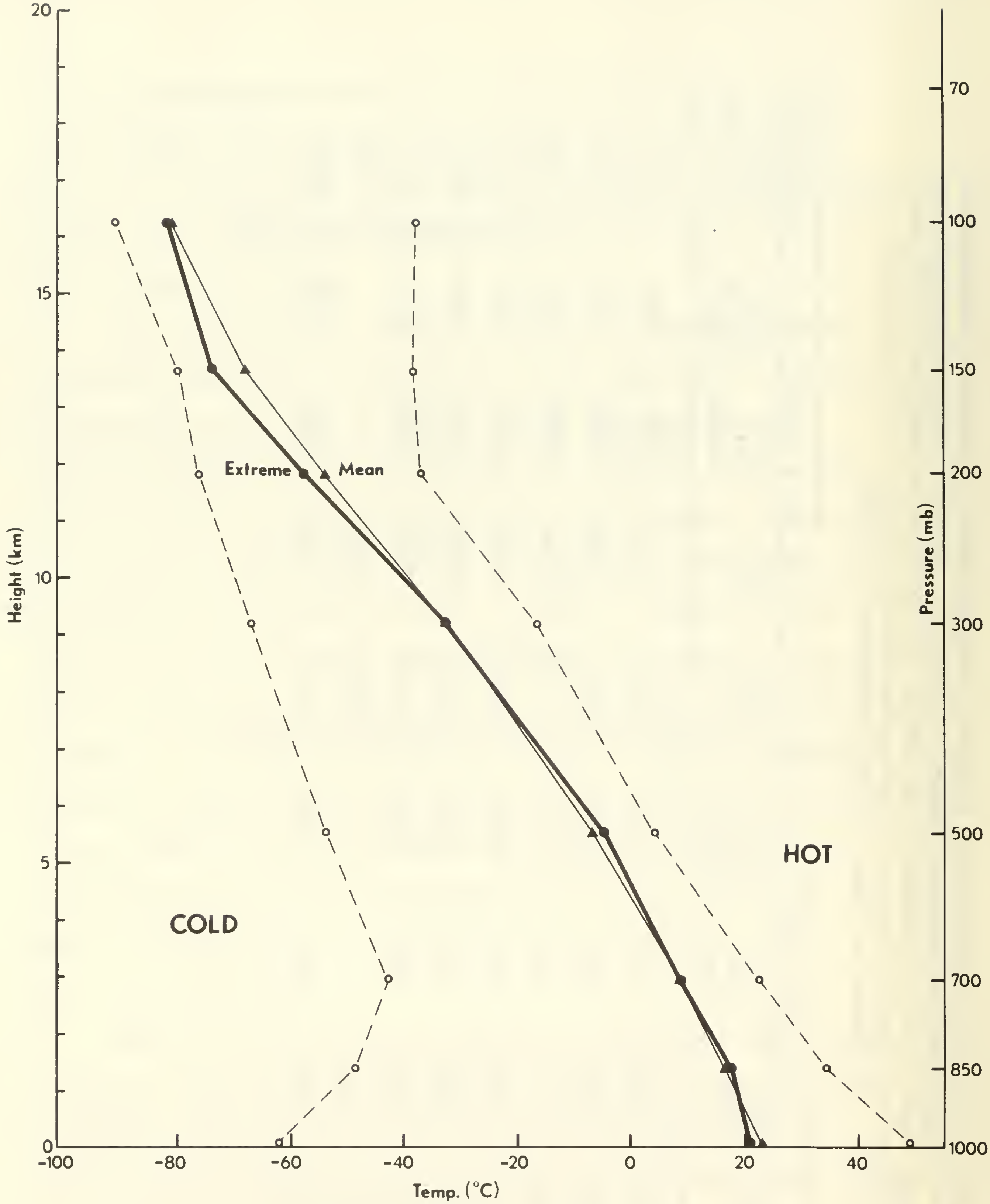

Fig. 5. Regression-generated mean January temperature profiles over Singapore corresponding to a forcing-level temperature $T_J(150)$. The heavy solid profile is based on the 1% cold extreme sample at 150 mb. Both profiles are based on values listed in Table 6.

TABLE 7. Regression statistics at mandatory pressure levels at New Delhi, India, using $T_J = T(150)$ as the forcing-level January temperature. Part (a) refers to the full-data January sample; part (b) refers to the nominal 10% cold extreme sample of T(150); part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme cold set of T(150). Data from rawinsondes in January, 1967-70.

Level	(a) N = 158 cases				(b) N = 11 cases				(c) N = 2
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T \leq T_{.01}$ $(T \leq -70.0)$
850 mb	9.16	2.764	.9833	0.516	10.93	3.406	.9935	0.388	14.4
700 mb	0.04	3.185	.9907	0.446	1.19	2.810	.9679	0.706	3.4
500 mb	-16.85	3.115	.9951	0.317	-14.63	3.090	.9898	0.439	-12.9
300 mb	-41.22	5.253	.9885	0.814	-37.26	5.664	.9552	1.677	-42.0
200 mb	-54.80	4.672	.9880	0.741	-55.50	2.287	.9599	0.642	-58.1
150 mb	-61.62	3.743			-68.26	1.385			-70.7
100 mb	-68.28	4.507	.9181	1.833	-74.54	3.712	.9240	1.419	-71.6
Sfc, 990.7 mb	19.03	2.022	(35 cases, 1200 GMT)						
991.4 mb	8.38	2.437	(57 cases, 0000 GMT)						
991.1 mb	12.43	5.654	(92 cases, both times)						

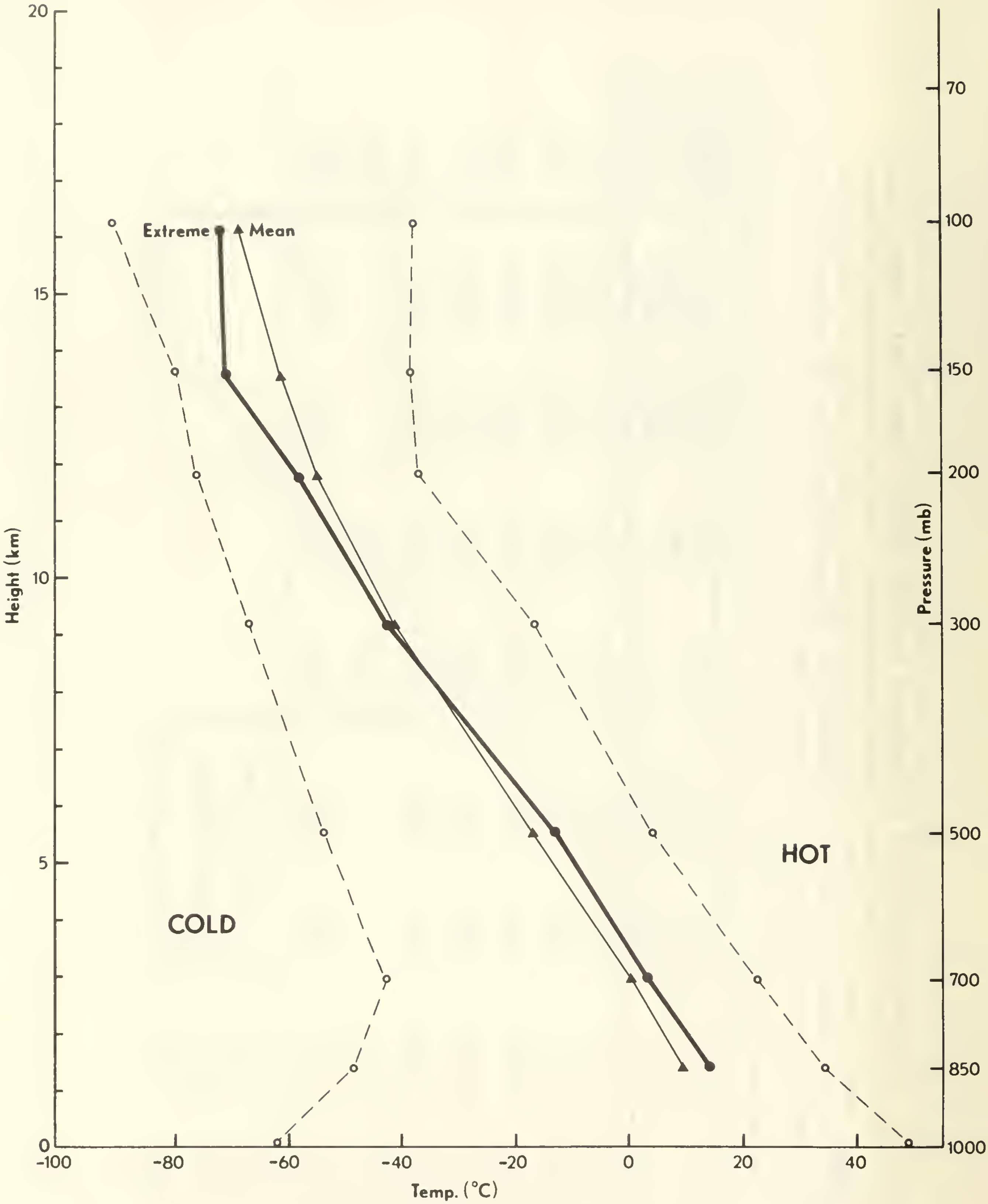

Fig. 6. Regression-generated mean January temperature profiles over New Delhi corresponding to a forcing-level temperature $T_J(150)$. The heavy solid profile is based on the 1% cold extreme sample at 150 mb. Both profiles are based on Table 7. The extension below 850 mb is included in Table 7.

to Karachi at 150 mb, which seems to be due to unreliable instrumentation. The 1% extreme $T_J(150) = -70.7\ ^oC$ observed here for New Delhi (Table 7) is considerably warmer than that found at Singapore, and therefore Singapore should qualify in place of Karachi as approximately representative of a world-wide cold extreme at 150 mb.

The surface regression at New Delhi has not been carried out. It is clear from the listed means and standard deviations at the surface (Table 7) that the diurnal variation tends to obscure interdiurnal variations. This presumably is a characteristic of the winter monsoon regime at this location. Fig. 6 indicates that the vertical profile for a New Delhi cold extreme $T_{.01}(150)$ is associated with a cool upper troposphere (relative to the mean) with a reversal toward a warm lower troposphere below 300 mb.

3(F). Summary of cold extreme regions

Recalling the results of <u>Model Atmospheres</u> (I) in conjunction with the present study, we can draw two well-defined distinctions. The coldest temperatures at 100 mb and possibly at 150 mb are to be found in equatorial regions. The coldest temperatures between 700 mb and 200 mb are found in extreme conditions in the Arctic circle under cold vortex (aloft) conditions, this temperature regime being somewhat more extreme than that found at Ojmjakon. The latter station, however, is consistently cold aloft at all of these levels, whereas the Arctic circle stations tend to undergo periodic "explosive warmings" even in January above 500 mb. Of course, the coldest surface stations (up to 850 mb) are found in the landlocked areas of Siberia.

4. <u>Development of regression-generated warm profiles, July extremes</u>.

The regression procedure of Section 3 was followed here with the July data-files of Insalah, Baghdad and New Delhi using appropriate forcing-level

temperatures T_J in deriving specification equations for each mandatory level $T_M \neq T_J$. In general a discussion of the results in the order T_J(Sfc), T_J(850), ..., T_J(300) will be given below.

4(A). Insalah, T_J(Sfc).

The results of the regression procedure on the full-sample data and the nominal 10% extreme sample are given in Table 8. In this case, $T_{.01}$(Sfc) was not observed; in fact was not really closely approached. This was due to the fact that the sounding record of the first level retrieved averaged approximately 40 meters above the station elevation. At this level, the amplitude of the diurnal temperature was much reduced so as to be unrepresentative of the Table 1 listing of the surface warm extreme temperature. The $T_{.01}$(Sfc) = 43.7 ^{o}C value listed under Table 8(c) is associated with a 1% histogram count from the actual distribution of "surface" temperatures. Fig. 7 shows that the $\overline{T}_M$(c) mean profile is considerably cooler in the upper troposphere than is $\overline{T}_M$(a).

4(B). Insalah, T_J(850).

Here the suggested extreme of Table 1 was observed, as is evident from $\overline{T}_M$(c) = 34.7 ^{o}C of Table 9(c). The $\overline{T}_M$(c)-profile which was correlated with this $T_{.01}$(850) then turns out to be consistently warmer than both $\overline{T}_M$(b) and $\overline{T}_M$(a), level for level. The fact that $\overline{T}_M$(c) is warmer than $\overline{T}_M$(a) is clearly depicted in Fig. 8. The most unusual feature of the $\overline{T}_M$(c)-profile is the relatively cool value at the surface T_M(Sfc) = 41.7^{o}C, indicating a possible association with a local storm effect.

4(C). Baghdad, T_J(Sfc).

Although Baghdad is suggested as having the extreme warm value at 700 mb (Table 1), it turned out that the Baghdad data listed <u>surface</u> temperatures as <u>hot</u> as that suggested for the 1% warm extreme (Table 1)

occurring in the Algerian desert. Thus the data for Baghdad was also used for $T_J(\mathrm{Sfc})$ since that for Insalah was inconclusive in this respect. It turned out that the radiosonde surface temperatures were well coordinated with shelter temperature values, and two reports of 49°C did occur in this area of the Iraqi desert. The corresponding profiles are listed in Table 10 for the (a), (b), (c) stratifications. Fig. 9 is indicative of the variation between the extreme and the full-sample case, and shows only slightly warmer temperatures in the former case at all mandatory levels. As noted in some previous comparisons the difference between the 10% and 1% "extreme" cases seems to be insignificant.

4(D). Baghdad, $T_J(700)$, 0000 GMT

Here the suggested nominal value of $T_{.01}(700)$ given by Eq. 7 was exceeded upon two separate occasions. Oddly, this occurred only with the 0000 GMT reports, the warmest 1200 GMT $T_J(700)$ reports being somewhat cooler. Hence, a separate analysis of the two different sets of sounding times at Baghdad was made and is summarized in Tables 11, 12. The tendency for a warm extreme $T_{.01}(700)$ to occur at night suggests that nighttime subsidence may be occurring at the 700 mb level following the maximum insolation during the preceding day. Fig. 10 shows that the tropopause temperature tends to be cooler aloft under these same conditions, i.e. $\overline{T}_{Mc}(100) < \overline{T}_{Mb}(100) < \overline{T}_{Ma}(100)$, and that this same trend is in effect all all upper levels $p \leq 200$ mb. Thus following a day of insolational maximum, the statistics suggest the concomitant occurrences of high-level tropospheric convergence with 700-mb subsidence. Both of these features tend to support the differences between profiles (a), (b) and (c).

TABLE 8. Regression statistics at mandatory pressure levels at Insalah, Algeria, using $T_J = T(Sfc)$ as the forcing-level July temperature. Part (a) refers to the full-data July sample; part (b) refers to the nominal 10% warm extreme sample of T(Sfc); part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme warm set of $T(_{Sfc})$. All reports are based upon 1200 GMT rawinsondes (1967-70).

Level	(a) N = 72 cases				(b) N = 6 cases				(c) N = 2
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \geq T_{.01}$
*P = 978.6 mb	39.14	3.035			43.32	0.355			43.70
850	27.49	2.827	.9755	0.661	29.63	1.322	.9135	0.538	29.15
700	13.91	1.939	.9271	0.772	14.13	0.838	.6580	0.631	13.55
500	-6.50	2.681	.9392	0.978	-7.58	1.669	.8672	0.831	-7.65
300	-30.23	3.127	.9821	0.625	-33.12	1.354	.7393	0.912	-32.95
200	-47.99	3.049	.9866	0.528	-51.13	1.577	.9779	0.329	-52.65
150	-58.69	3.049	.9736	0.738	-61.47	3.636	.9940	0.398	-63.75
100	-67.73	3.288	.8952	1.555	-69.68	3.470	.9504	1.079	-71.40

*mean height of rawinsonde release is 283.6 meters

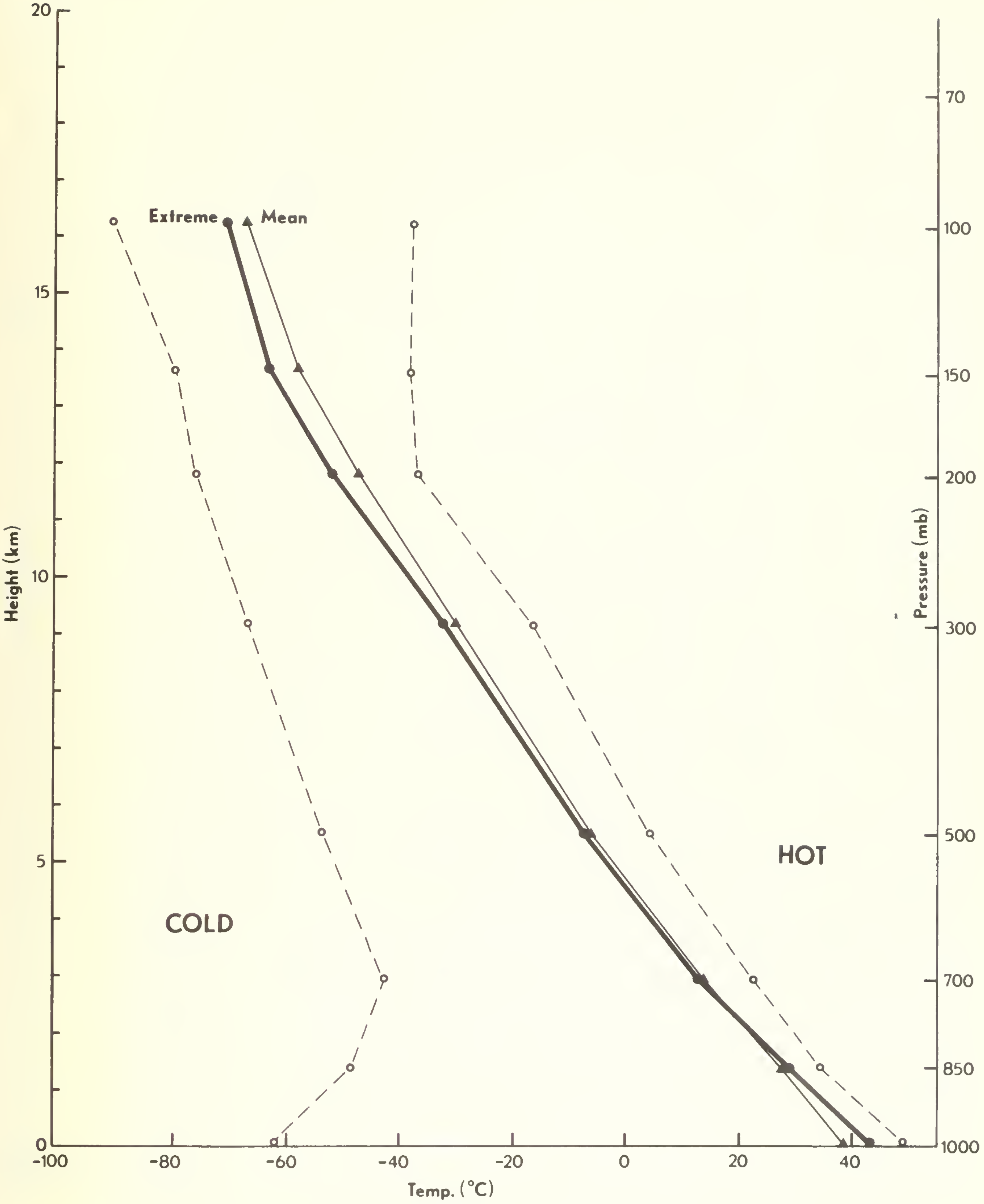

Fig. 7. Regression-generated mean July temperature profiles over Insalah, Algeria, corresponding to a forcing-level temperature T_J(Sfc). The heavy solid profile is based on the 1% extreme warm sample at the surface. Both profiles are based on Table 8.

TABLE 9. Regression statistics at mandatory pressure levels at Insalah, Algeria, using $T_J = T(850)$ as the forcing-level July temperature. Part (a) refers to the full-data July sample; part (b) refers to the nominal 10% warm extreme sample of T(850); part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme warm set of T(850). All reports are from 1200 GMT rawinsondes (1967-70).

Level	(a) N = 72 cases				(b) N = 6 cases				(c) N = 2
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \geq T_{.01}$
978.6 mb	39.14	3.035	.9593	0.909	41.18	2.132	.8738	1.037	41.7
850	27.49	2.827			32.27	2.133			34.7
700	13.91	1.939	.9252	0.781	16.53	1.440	.9525	0.439	18.1
500	-6.50	2.681	.9395	0.976	-5.98	1.780	.7882	1.096	-4.55
300	-30.23	3.127	.9813	0.639	-29.97	4.225	.9927	0.508	-26.2
200	-47.99	3.049	.9866	0.528	-47.62	3.562	.9949	0.358	-44.1
150	-58.69	3.049	.9729	0.748	-56.92	3.051	.9670	0.777	-55.05
100	-67.73	3.288	.8960	1.550	-66.52	2.770	.9012	1.201	-64.4

*mean height of rawinsonde release is 283.6 meters

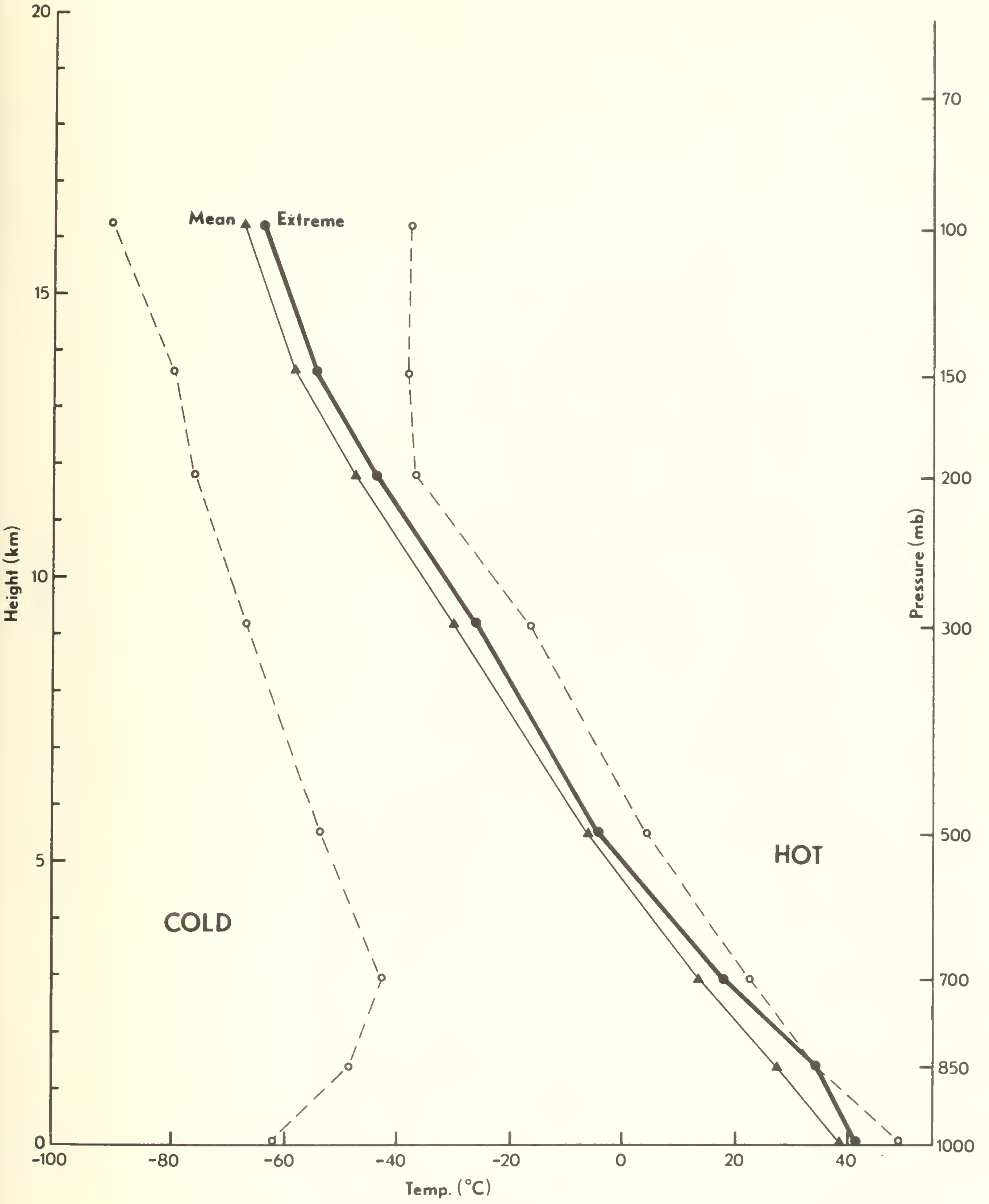

Fig. 8. Regression-generated mean July temperature profiles over Insalah corresponding to a forcing-level temperature $T_J(850)$. The heavy solid profile is based on the 1% extreme warm sample at 850 mb. Both profiles are based on Table 9.

TABLE 10. Regression statistics at mandatory pressure levels at Baghdad, Iraq , using $T_J = T(Sfc)$ as the forcing-level July temperature. Part (a) refers to the full-data July sample; part (b) refers to the nominal 10% warm extreme sample of T(Sfc); part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme warm set of $T(_{Sfc})$. All reports listed here are based upon 1200 GMT rawinsondes (1967-70).

Level	(a) N = 42 cases				(b) N = 6 cases				(c) N = 2
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \geq T_{.01}$
995.5mb	43.18	3.031			48.12	0.778			49.1
850	27.05	2.490	.9923	0.344	29.55	3.667	.9990	0.165	28.0
700	13.98	2.461	.9531	0.830	16.53	2.972	.9831	0.543	15.6
500	-2.18	2.898	.9373	1.126	-1.32	2.076	.9115	0.854	-1.55
300	-26.73	2.183	.9817	0.464	-26.60	2.616	.9986	0.139	-26.50
200	-45.42	1.760	.9950	0.196	-45.35	1.253	.9998	0.028	-44.85
150	-58.36	2.093	.9971	0.179	-57.85	1.717	.9972	0.128	-56.80
100	-72.88	2.539	.9813	0.544	-71.75	2.679	.9928	0.321	-69.25

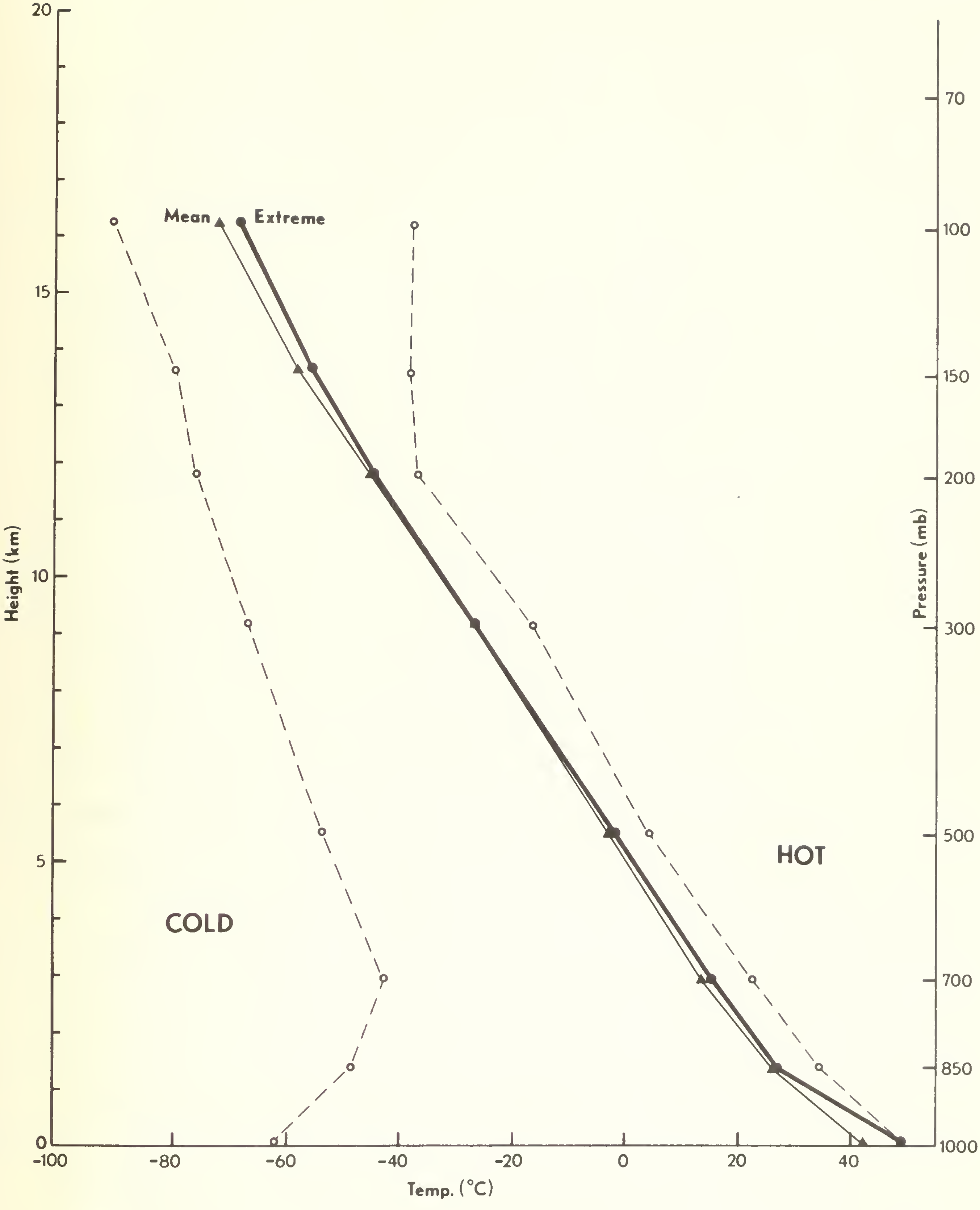

Fig. 9. Regression-generated mean July temperature profiles over Baghdad, Iraq, corresponding to a forcing-level temperature T_J(Sfc) at 1200 GMT. The heavy solid line is based on the 1% extreme warm sample at the surface. Both profiles are based on Table 10.

4(E). Baghdad, $T_J(700)$, 1200 GMT.

The results in this case are listed in Table 12, with an extreme warm $T_J(700) = 19.7\ ^\circ C$, which is lower than the 0000 GMT extreme. However, the case (c) surface temperature $\overline{T}_{Mc}(Sfc) = 49.0\ ^\circ C$ corresponds to the daytime $T_J(Sfc)$ extreme. Table 12 and Fig. 11 both show the $\overline{T}_M(c)$ profile to be slightly warmer at all levels than the $\overline{T}_M(b)$ and $\overline{T}_M(a)$ profiles at 1200 GMT. In contrast with the 0000 GMT profile-extreme, the 1200 GMT is dominated by convection at all tropospheric levels in view of the strong surface layer lapse. In fact this case resembles that of $T_J(850)$ at Insalah, apart from the surface-level perturbation of temperature at Insalah.

The Baghdad 1200 GMT data file revealed no occurrence of a warm extreme at 850 mb which equalled that observed over the Algerian desert (Insalah). Consequently, the problem of generating a model atmosphere $\overline{T}_M(c)$ based upon the contingent condition of a $T_{.01}(850)$ at Baghdad was not considered. In fact comparison of Tables 8 and 10 show that apart from the surface and 700 mb levels the Insalah midday profile at all other levels is warmer than that over Baghdad. The apparent difference at the surface has been explained in Section 4(A), and the explanation of a 700-mb extreme at Baghdad has evidently to do with stronger anticyclonic control aloft which manifests itself clearly in the 0000 GMT soundings.

4(F). New Delhi, $T_J(500)$ and $T_J(300)$.

These cases should first be reviewed separately as summarized in Tables 13 and 14, respectively. It should be noted that the proposed $T_{.01}(500) = 4\ ^\circ C$ of Table 1 was not observed at New Delhi. This Table 1 overestimate seems to be due to an overestimate of the standard deviation in conjunction with Eq. 7. However, it is significant to note that Table 13

TABLE 11. Regression statistics at mandatory pressure levels at Baghdad, Iraq , using $T_J = T(700)$ as the forcing-level July temperature. Part (a) refers to the full-data July sample; part (b) refers to the nominal 10% warm extreme sample of T(700); part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme warm set of T(700). All reports listed here are based upon 0000 GMT rawinsondes (1967-70).

Level	(a) N = 50 cases				(b) N = 5 cases				(c) N = 2
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \geq T_{.01}$
995.5 mb	29.52	2.873	.5987	2.456	31.28	2.989	.8403	1.621	33.55
850	26.47	2.388	.9656	0.663	28.76	1.769	.7644	1.140	28.40
700	14.08	3.018			19.32	1.390			20.60
500	-2.24	2.408	.9373	0.896	-2.42	2.404	.8955	1.069	-4.80
300	-26.21	2.155	.9593	0.650	-26.64	2.306	.9704	0.557	-25.70
200	-46.07	1.809	.9964	0.163	-46.12	0.976	.9977	0.066	-46.40
150	-59.23	1.800	.9954	0.185	-59.68	1.031	.9917	0.125	-60.30
100	-74.10	2.193	.9224	0.904	-75.50	2.107	.8484	1.115	-77.20

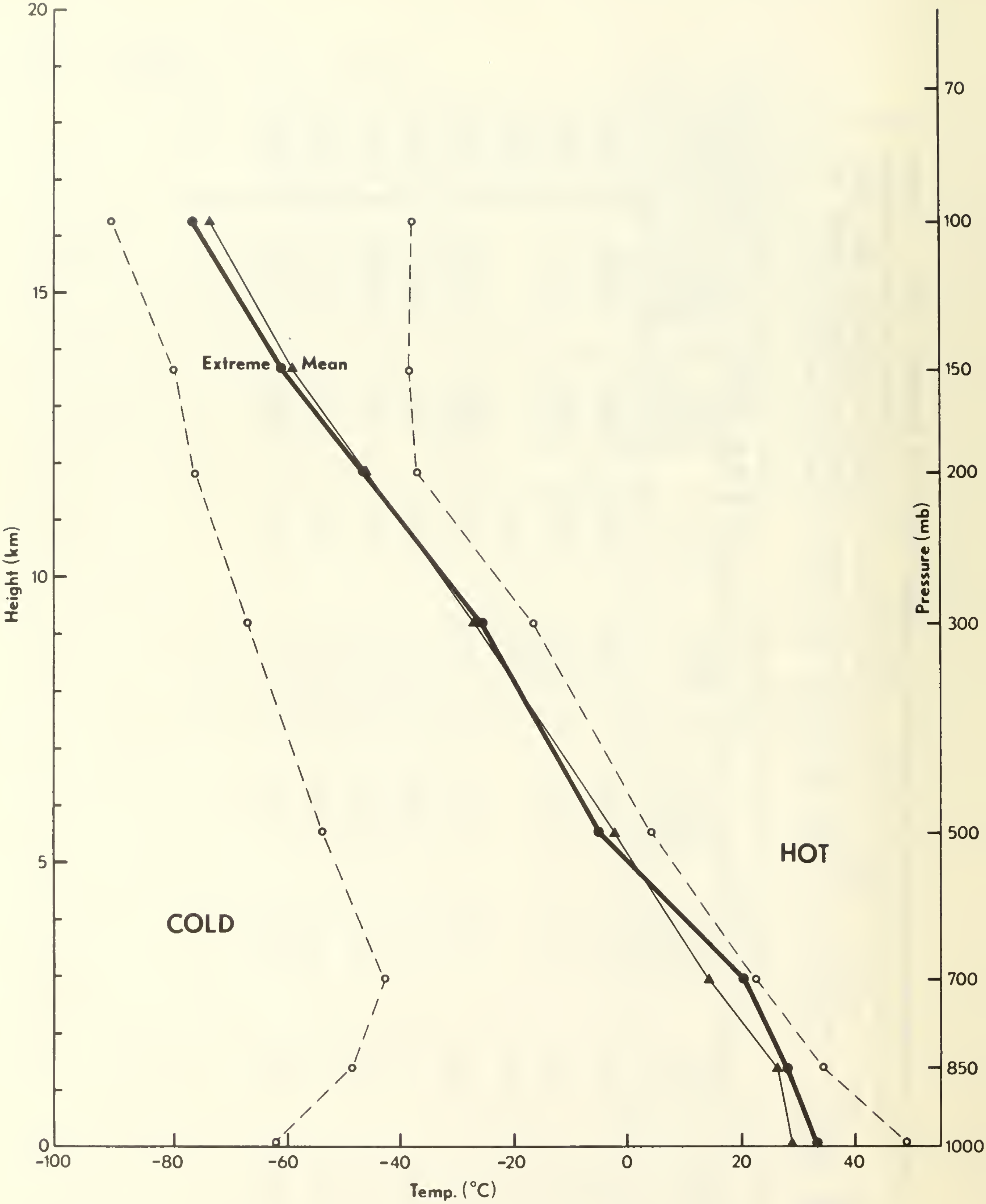

Fig. 10. Regression-generated mean July temperature profiles over Baghdad corresponding to a forcing-level temperature $T_J(700)$ at 0000 GMT. The heavy solid profile is based on a 1% extreme warm sample at 700 mb. Both profiles are based on Table 11.

TABLE 12. Regression statistics at mandatory pressure levels at Baghdad, Iraq , using $T_J = T(700)$ as the forcing-level July temperature. Part (a) refers to the full-data July sample; part (b) refers to the nominal 10% warm extreme sample of T(700); part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme warm set of $T(_{700})$. All reports listed here are from 1200 GMT rawinsondes (1967-70).

Level	(a) N = 40 cases				(b) N = 4 cases				(c) N = 1
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \geq T_{.01}$
995.5 mb	43.18	3.031	.8654	1.693	46.77	2.608	.9436	0.864	49.0
850	27.05	2.490	.9924	0.342	30.72	2.368	.9980	0.151	30.2
700	13.98	2.461			18.62	0.818			19.7
500	-2.18	2.898	.9494	1.015	-3.70	5.449	.9849	0.944	0.2
300	-26.73	2.183	.9793	0.492	-26.57	1.672	.9951	0.165	-25.5
200	-45.42	1.760	.9949	0.197	-44.62	1.357	.9996	0.037	-44.2
150	-58.36	2.093	.9972	0.173	-56.57	2.161	.9981	0.134	-56.5
100	-72.88	2.539	.9824	0.529	-71.72	2.969	.9920	0.375	-70.8

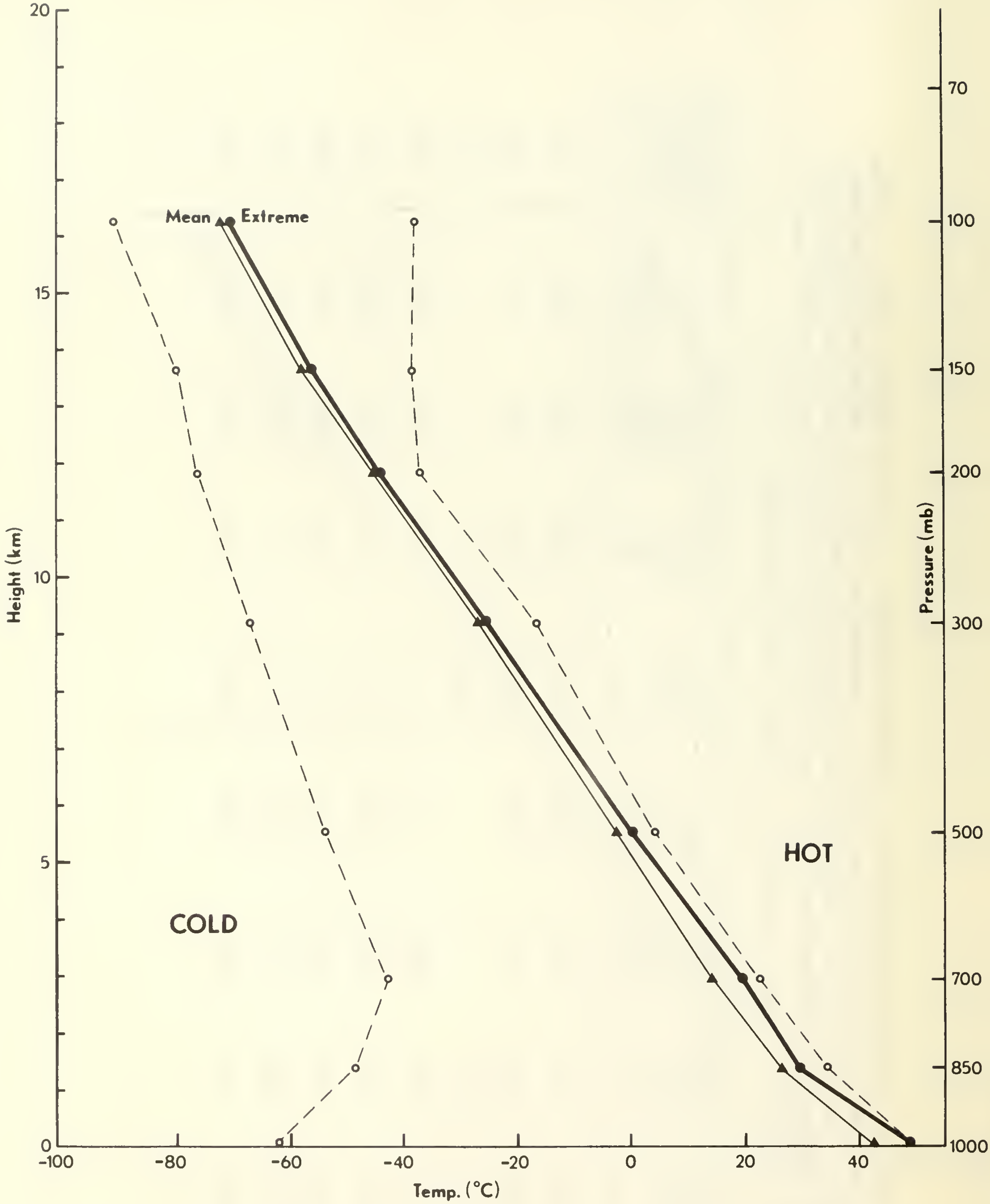

Fig. 11. Regression-generated mean July temperature profiles over Baghdad corresponding to a forcing-level temperature $T_J(700)$ at 1200 GMT. The heavy solid profile is based on a 1% extreme warm sample at 700 mb at 1200 GMT. Both profiles are based on Table 12.

TABLE 13. Regression statistics at mandatory pressure levels at New Delhi, India, using $T_J = T(500)$ as the forcing-level July temperature. Part (a) refers to the full-data July sample; part (b) refers to the nominal 10% warm extreme sample of T(500); part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme warm set of T(500). Based upon twice-daily rawinsondes observed during 1967-70.

Level	(a) N = 159 cases				(b) N = 21 cases				(c) N = 2
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \geq T_{.01}$
1000 mb *	29.93	3.773	.9879	0.601	31.60	4.483	.9823	0.884	27.95
850	22.99	2.047	.9813	0.405	24.39	2.138	.9876	0.354	22.70
700	12.75	1.472	.9555	0.446	13.43	1.692	.9377	0.620	13.70
500	-1.75	1.573			.52	0.336			1.20
300	-25.38	1.989	.9728	0.473	-23.66	2.021	.9763	0.461	-24.80
200	-48.05	3.001	.9927	0.371	-45.63	2.985	.9947	0.322	-49.30
150	-63.08	3.963	.9915	0.530	-60.41	4.089	.9968	0.345	-65.70
100	-75.68	2.957	.8018	1.814	-75.07	3.937	.9168	1.657	-79.60

*mean station pressure level is 971.6 mb, at 219.8 meters elevation

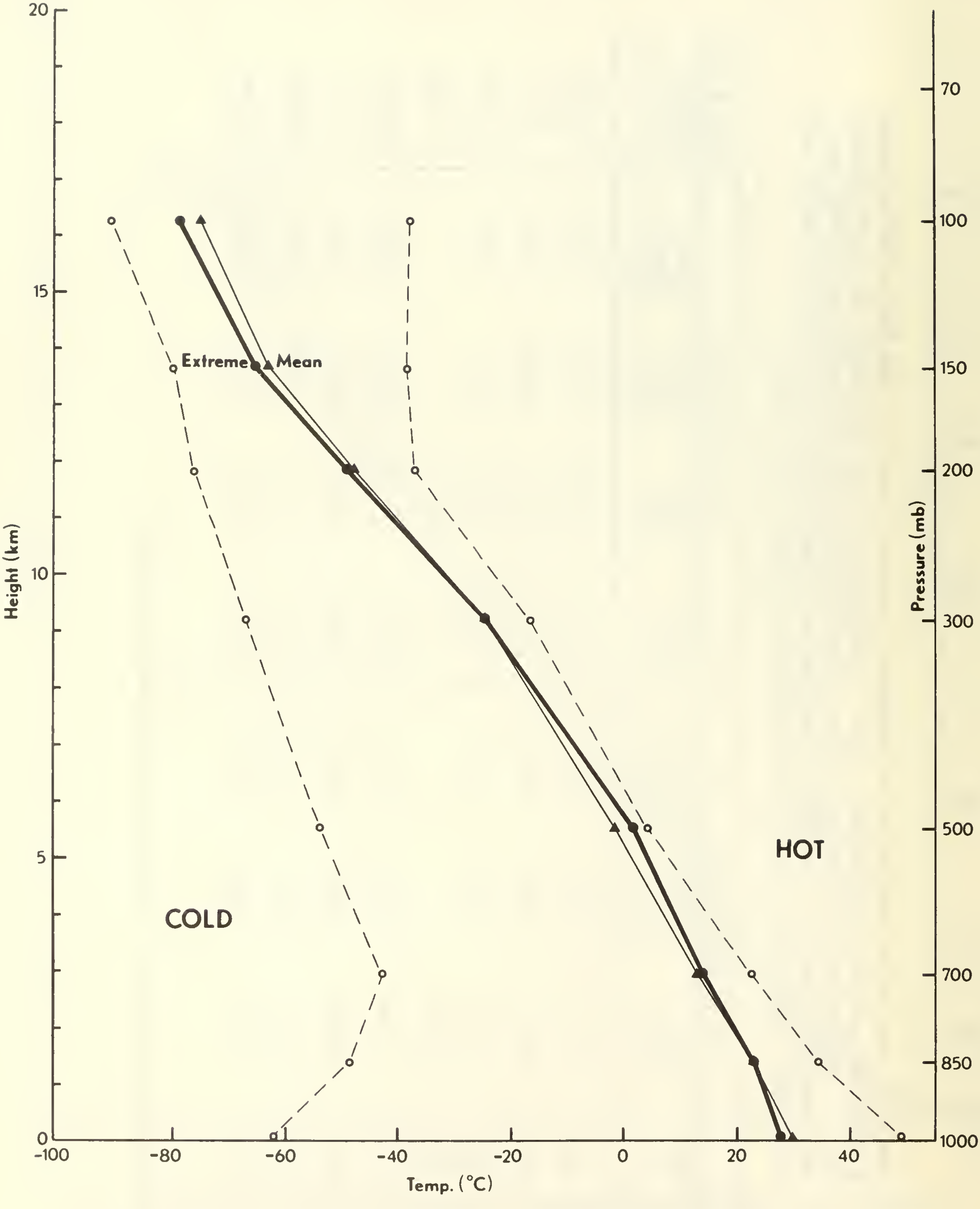

Fig. 12. Regression-generated mean July profiles over New Delhi corresponding to a forcing-level temperature $T_J(500)$. The heavy solid profile is based upon a 1% extreme warm sample at 500 mb. Both profiles are based on Table 13.

TABLE 14. Regression statistics at mandatory pressure levels at New Delhi, India, using $T_J = T(300)$ as the forcing-level July temperature. Part (a) refers to the full-data July sample; part (b) refers to the nominal 10% warm extreme sample of $T_J(300)$; part (c) lists the sounding-level mean temperatures corresponding to the 1% extreme warm set of $T_J(300)$. Based upon a set of twice-daily rawinsondes (1967-70).

Level	(a) N = 159 cases				(b) N = 18 cases				(c) N = 2
	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Mean °C	Std. Dev. °C	Mult. Corr. Coeff.	Std. Err. of Est, °C	Means $T_J \geq T_{.01}$
1000 mb*	29.93	3.773	.9879	0.601	31.19	4.671	.9719	1.171	27.6
850	22.99	2.047	.9814	0.403	24.72	1.667	.9677	0.448	24.3
700	12.75	1.472	.9555	0.446	14.15	1.512	.8957	0.715	14.3
500	-1.75	1.573	.9020	0.697	-.45	1.290	.6809	1.006	-0.60
300	-25.38	1.989			-21.98	0.738			-20.6
200	-48.05	3.001	.9928	0.370	-43.50	1.477	.9863	0.260	-41.75
150	-63.08	3.963	.9912	0.537	-58.30	2.187	.9839	0.417	-56.80
100	-75.68	2.957	.8045	1.803	-74.91	3.469	.9132	1.505	-75.45

*mean station pressure level is 971.6 mb at 219.8 meters elevation

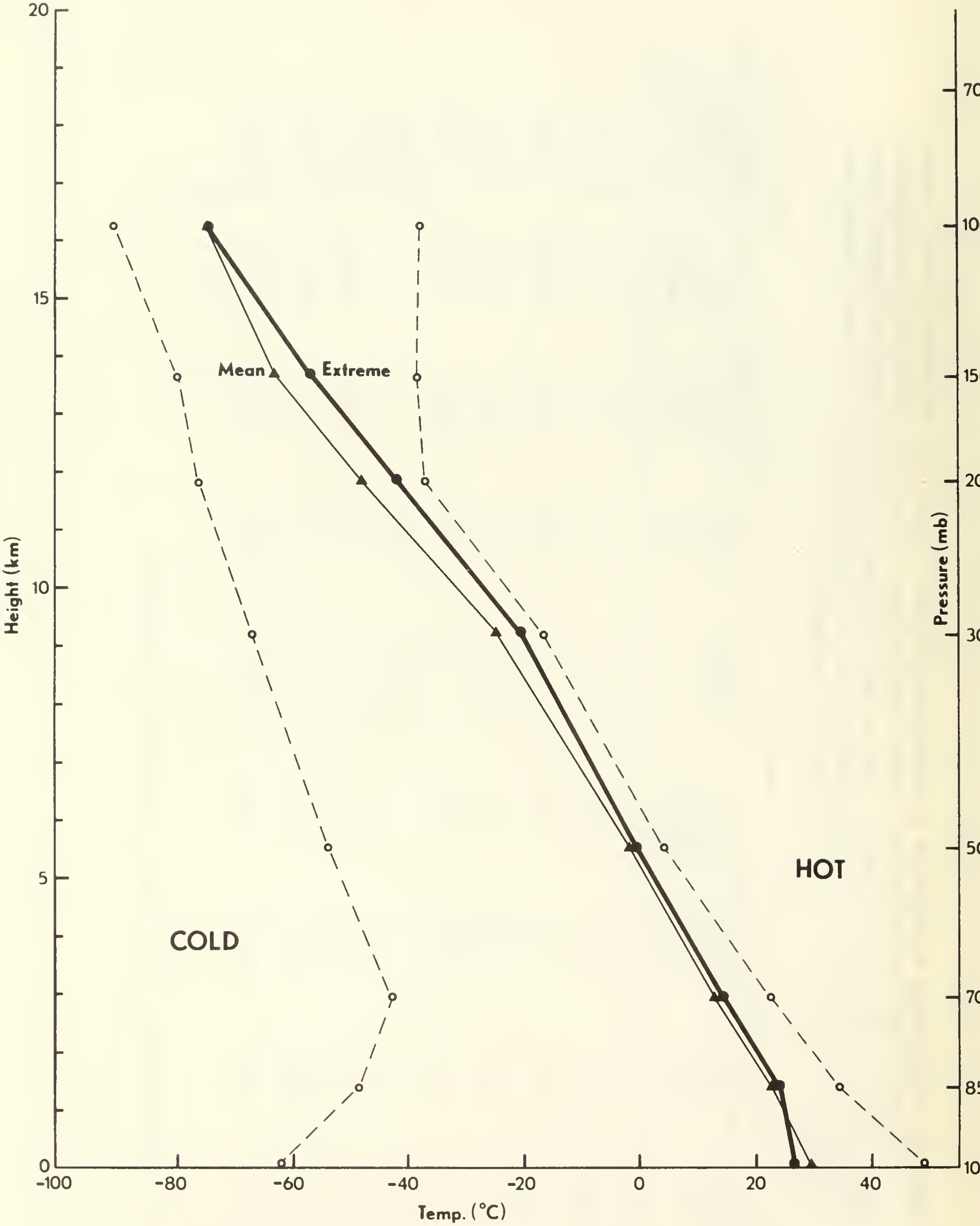

Fig. 13. Regression-generated mean July temperature profiles over New Delhi, corresponding to a forcing-level temperature $T_J(300)$. The heavy solid profile is based on the 1% extreme warm sample at 300 mb. Both profiles are based on Table 14.

does indicate a shift in warmest July 500 mb temperatures from Baghdad to New Delhi. This phenomenon of $T_{.01}(500)$ at New Delhi is evidently associated with the summer monsoon circulation over New Delhi and its associated release of latent heat at the forcing level $T_J(500)$.

In the case of an extreme forcing-level temperature at the 300 mb level, latent heat release goes on to much higher levels. Hence the $\bar{T}_M(b)$, $\bar{T}_M(c)$ profiles of Table 14 are warmer above 300 mb than those of Table 13. These features of the "extreme" New Delhi soundings are credible in view of the summer monsoon effect. Note that in both extreme profiles of Fig. 12 and Fig. 13, respectively, the surface level "extreme" data are cooler than those of the full-sample means, presumably because of reduced surface precipitation in the full-sample case (a).

5. Conclusions

The data treated in this study is in general based upon less sounding data than that of Model Atmospheres (I). As a result in addition to checking the data for hydrostatic consistency, they have been checked for also meteorological reality wherever possible. In general, the locations of extreme temperature sites are located as originally suggested (Sissenwine, 1970, personal communication). More specifically, some of the original 1% extremes of Table 1 appear to have been overestimated (warm cases) or underestimated, depending upon the validity of the standard deviation. The data-processing employed in this study seems to have generated more realistic standard deviations as well as means.

A further effort along the lines of Model Atmospheres (I) and the current study is anticipated for a set of Oceanic Station Vessels and for several island stations where oceanic extremes (rather than world-wide) are known to occur.

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13. ABSTRACT

In an earlier paper (Model Atmospheres (I)), a procedure was developed for determining the most probable vertical temperature profile associated with the occurrence of 1% global temperature extreme at mandatory-pressure levels at stations in the North American Arctic. The same technique, based upon a variation of the stepwise multiple regression procedure, was employed in the current study. Whereas the radiosondes investigated in Model Atmospheres (I) consisted entirely of "checked-data" quality, those stations designated for study in this work required a much more refined data-screen, due to lack of initially checked radiosonde report quality. Nevertheless, after application of various acceptability criteria, the radiosondes at each station were arranged in the same format as employed in Model Atmospheres (I). There remained in each case a suitable sample population to provide significant results. The ensuing multiple regression analysis applied to the geographically and climatologically diverse set of stations of the current study led to realistic estimates of the temperature profiles which were conditionally dependent upon the existence of 1% extreme forcing-level temperature T_J at previously designated pressure levels p_J.

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